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A Study of the Ultraviolet Absorptions  
in the Spectra of DA White Dwarfs

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## ABSTRACT

During the interval of time, April 1, 1985 to September 30, 1985, the research effort connected with Grant NAG5-287 from the National Aeronautics and Space Administration has been to study the properties of the  $\lambda\lambda 1600$  and  $1400$  absorptions in the ultraviolet spectra of the hydrogen rich DA white dwarfs using the *International Ultraviolet Explorer* satellite and to search for additional new spectroscopic features, the observed properties of which can be matched quite well with the absorptions of the  $H_2$  and  $H_2^+$  quasi-molecules.

## I. INTRODUCTION

The purpose of the research reported here has been to continue systematic observations of the ultraviolet spectra of the hydrogen-rich DA white dwarfs with the *International Ultraviolet Explorer* satellite (*IUE*). This is to follow up on the work reported in Nelan and Wegner (1985) that the strong absorptions found earlier near  $\lambda\lambda$  1600 and 1400 (Cf. Greenstein 1980; Wegner 1982 and 1984a,b) in the spectra of the cooler DA are absorptions produced by the  $H_2$  and  $H_2^+$  quasi-molecules.

Observations of new DA white dwarfs summarized in Table I were obtained with the *IUE* under the auspices of NASA grant NAG5-287. Some of the results have been presented as papers and are listed in Appendix I.

## II. OBSERVATIONAL RESULTS

These ultraviolet spectra of DA white dwarfs with the *IUE* have revealed the existence of a number of ultraviolet spectroscopic features that were not previously suspected from the classical ground based observations in the visible. This began with Greenstein's (1980) discovery of the  $\lambda$ 1400 feature in the spectrum of the well studied  $T_{\text{eff}} = 16,900$  °K DA star 40 Eri B. Subsequently, this depression was observed in the ultraviolet spectra of numerous other DA white dwarfs with varying degrees of

Table 1

Objects Observed with *IUE* under the Auspices of Grant NAG5-287  
(July 11, 1983-July 29, 1985)

<u>White Dwarf/ Coordinates</u>	<u>Date of <i>IUE</i> Observation</u>	<u>Image No.</u>	<u>Spectral Type</u>
L481-06	Jul. 11, 1983	SWP20441	DA
L481-06	Jul. 11, 1983	LWR16327	DA
BPM1266	Jul. 11, 1983	SWP20442	DA
BPM1266	Jul. 11, 1983	LWR16328	DA
L19-2	Jul. 11, 1983	SWP20443	DA
L19-2	Jul. 11, 1983	LWR16329	DA
0039+04	Jul. 11, 1983	SWP20444	sd
0039+04	Jul. 11, 1983	LWR16330	sd
0039+04	Jul. 11, 1983	SWP20445	sd
GD279	Jul. 11, 1983	SWP20446	DA
GD279	Jul. 11, 1983	LWR16331	DA
G2-17	Jan. 22, 1984	LWP2695	DA
G2-17	Jan. 22, 1984	SWP22077	DA
G8-8	Jan. 22, 1984	LWP2696	DA
G8-8	Jan. 22, 1984	SWP22078	DA
GD64	Jan. 22, 1984	LWP2697	DA
GD64	Jan. 22, 1984	SWP22079	DA
L870-2	Jul. 1, 1984	LWP3695	DA
L870-2	Jul. 1, 1984	SWP23380	DA
BPM2819	Jul. 2, 1984	LWP3697	DA
BPM2819	Jul. 2, 1984	LWP3698	DA
BPM2819	Jul. 2, 1984	SWP 23381	DA
L997-21	Aug. 29, 1984	SWP23819	DA
L997-21	Aug. 29, 1984	LWP4102	DA
BPM2819	Aug. 30, 1984	SWP23820	DA
BPM2819	Aug. 30, 1984	LWP4103	DA
BPM2819	Aug. 30, 1984	SWP23821	DA
LFT158	Jul. 29, 1985	LWP6516	DA
LFT158	Jul. 29, 1985	SWP26503	DA
LFT158	Jul. 29, 1985	LWP6517	DA
G240-51	Jul. 29, 1985	SWP26504	DA
LHS2594	Jul. 29, 1985	LWP6518	DA
LHS2594	Jul. 29, 1985	SWP26505	DA
G240-51	Jul. 29, 1985	LWP6519	DA

strength (Wegner 1982; 1984a,b; Sion et al. 1983). Basically, the observations show that  $\lambda 1400$  is prominent at effective temperatures near 13,000  $^{\circ}\text{K}$  and decreases in equivalent width for higher  $T_{\text{eff}}$ , reaching the limit of detectability with the low resolution mode of *IUE* near  $T_{\text{eff}} = 19000$   $^{\circ}\text{K}$  (Wegner 1984a).

For lower temperatures, i.e.  $T_{\text{eff}} < 13000$   $^{\circ}\text{K}$ , an additional clue was the discovery of the feature near  $\lambda 1600$  which begins to dominate the spectra of DA stars for  $T_{\text{eff}} < 12000$   $^{\circ}\text{K}$ . Although  $\lambda 1600$  occurs in the spectra of many DA stars hotter than this, its strength drops rapidly with increasing  $T_{\text{eff}}$ . Holm et al. (1983; 1985) reported this and it has been further described in Wegner (1984a,b). Some examples of DA stars of different effective temperature that show these ultraviolet depressions in their spectra are given in Figure 1.

A number of earlier theories regarding the origin of the  $\lambda\lambda 1400$  and  $1600$  absorptions were proposed, as summarized in Wegner (1984a,b), but all of them run into serious difficulties when considered in detail quantitatively. However, a quite natural explanation is that the observed ultraviolet depressions are produced by the quasi-molecular features of hydrogen and this identification was published in Nelan and Wegner (1985). Further details on the model atmospheres employed can be found in Nelan

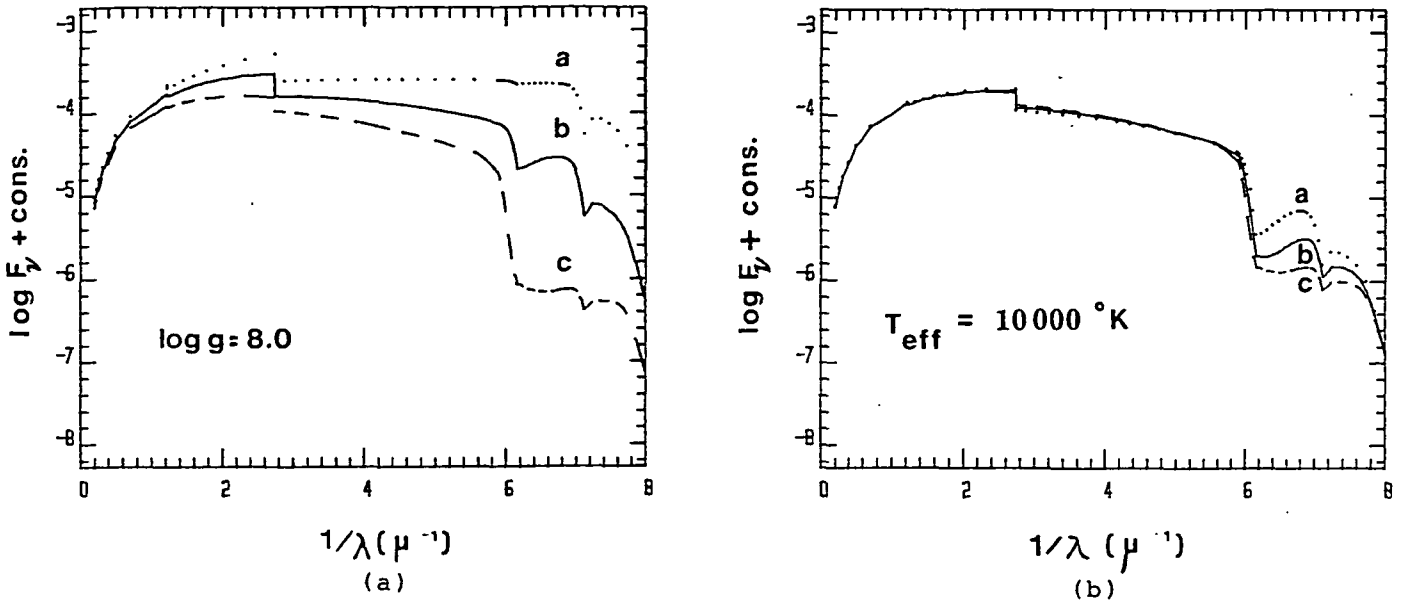
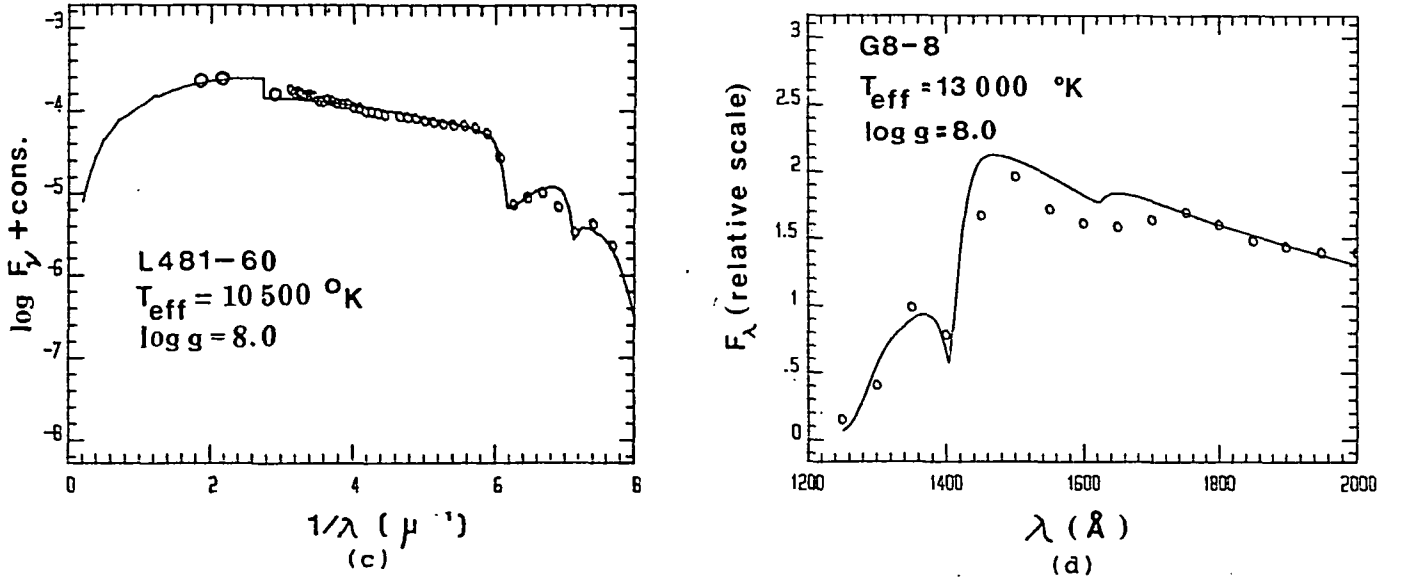


FIG. 1 - Ultraviolet spectral energy distributions from Nelan and Wegner (1985); (a) Computed energy distributions for pure hydrogen models with  $\log g = 8.0$  for  $T_{\text{eff}} =$  (a)  $12000^{\circ}\text{K}$ , (b)  $11000^{\circ}\text{K}$ , (c)  $9500^{\circ}\text{K}$ . Only continuum points are plotted although the calculations were carried out for fully line blanketed models.  
(b) The same as Fig. 10a, but at fixed  $T_{\text{eff}}$  and  $\log g =$  (a) 7.4, (b) 8.0, (c) 8.6.



(c) Comparison between the observed energy distribution of white dwarf L481-60 (WD1544-37) from Wegner (1984b) Shown as open circles and a pure H model with  $T_{\text{eff}}$  and  $\log g$  as indicated.  
(d) The same as Fig. 10c, except for the star G8-8 (WD0401+25).

(1985) which is a Ph. D. thesis partially based on the data obtained for this project. Holm et al. (1985) were the first to suggest  $\lambda 1600$  as the resonance broadening of the Ly  $\alpha$  line. Koester et al. (1985) have independantly presented conclusions similar to those reached in Nelan and Wegner (1985).

Quasi-molecular features are a well known spectroscopic effect, but one little used in astrophysics. In the case of the DA stars, the approach of two ground-state hydrogen atoms perturbs the  $n=1$  and  $n=2$  energy levels giving rise to the Ly $\alpha$  line broadening. However, for small interatomic differences, the conventional description for resonance broadening (Jeffreys 1968) is inappropriate. In Nelan and Wegner (1985), the semi-classical theory of Sando and Wormhoudt (1973) was applied to the hydrogen quasi-molecule. The maximum of the predicted features occurs near  $\lambda 1623$ . Similarly, the  $H_2^+$  quasi-molecule produces the strong satellite band to Ly  $\alpha$  at  $\lambda 1404.9$  with other weaker ones near  $\lambda \lambda 1233$  and  $1240$ . The absorption profile for this from Stewart, Peek, and Cooper (1973) has been included in the calculations.

The spectral energy distributions from the resulting model atmospheres reported in Nelan and Wegner (1985) agree well with the observed properties of  $\lambda \lambda 1600$  and  $1400$ . In this study, it was found that the use of fully line blanketed models was important. The

main results are summarized in Figure 1. In Figure 1a, the temperature dependance at  $\log g = 8$  can be seen. At relatively low  $T_{\text{eff}}$ ,  $\lambda 1600$  is strong, but fades rapidly in strength for temperatures above  $11000^\circ\text{K}$  with increasing hydrogen ionization. In agreement with the observations, the hydrogen ion quasi-molecular feature near  $\lambda 1400$  persists to higher  $T_{\text{eff}}$  since it is governed by both the proton and neutral hydrogen densities. Figure 1b shows the dependance of  $\lambda\lambda 1400$  and  $1600$  on gravity for  $T_{\text{eff}}$  fixed at  $10000^\circ\text{K}$ . Figures 1c and 1d compare the results from our models with the observed spectra of two stars from which it is concluded that in nearly all cases studied so far, pure hydrogen atmospheres without metals agree well with the observations.

### III. FURTHER OBSERVATIONS OF ULTRAVIOLET FEATURES IN THE SPECTRA OF THE DA WHITE DWARFS

Work on the  $\text{H}_2$  and  $\text{H}_2^+$  quasi-molecular features in the ultraviolet spectra of the cool DA stars by both obtaining new observations and producing more sophisticated model atmospheres is continuing. There appears to be ample room for such work because a large enough sample of interesting cool DAs that can be reached with the *IUE* still exists and in the spectra of some of the



objects already studied, additional spectroscopic features have been identified which it is hoped that the model atmospheres can eventually be used to explain.

Two examples of such objects recently observed and still under analysis are shown in Figures 2 and 3. The first star, L870-2 (=EG11), has been known to have an anomalously large radius on the basis of its photometry and trigonometric parallax as discussed in Schulz and Wegner (1980) who found  $T_{\text{eff}} = 7500 \text{ }^{\circ}\text{K}$  and  $\log R/R_{\odot} = -1.5$ . Greenstein, Boksenberg, et al. (1977) have also commented that  $H\alpha$  shows an emission core. This object is also discussed in Greenstein (1984). Figure 2 combines recent *IUE* ultraviolet spectra with ground based data from Oke (1974). None of the pure or mixed hydrogen and helium models from Nelan and Wegner (1985) can fit the energy distribution. One possible solution to this puzzle is that L870-2 is composite.

The second star, G2-17, has been described by Wegner and Nelan (1984) and its energy distribution can be fit with a  $T_{\text{eff}} = 8000 \text{ }^{\circ}\text{K}$  hydrogen model. Besides showing the strong cutoff at  $\lambda 1600$ , illustrated in Figure 3, this object displays a broad shallow depression near  $\lambda 2500$ . Also L870-2 seems to show a feature near  $\lambda 1800$ . Consequently, the search for additional ultraviolet spectroscopic features should be continued and it is intended to continue to utilize the *IUE* to systematically search the

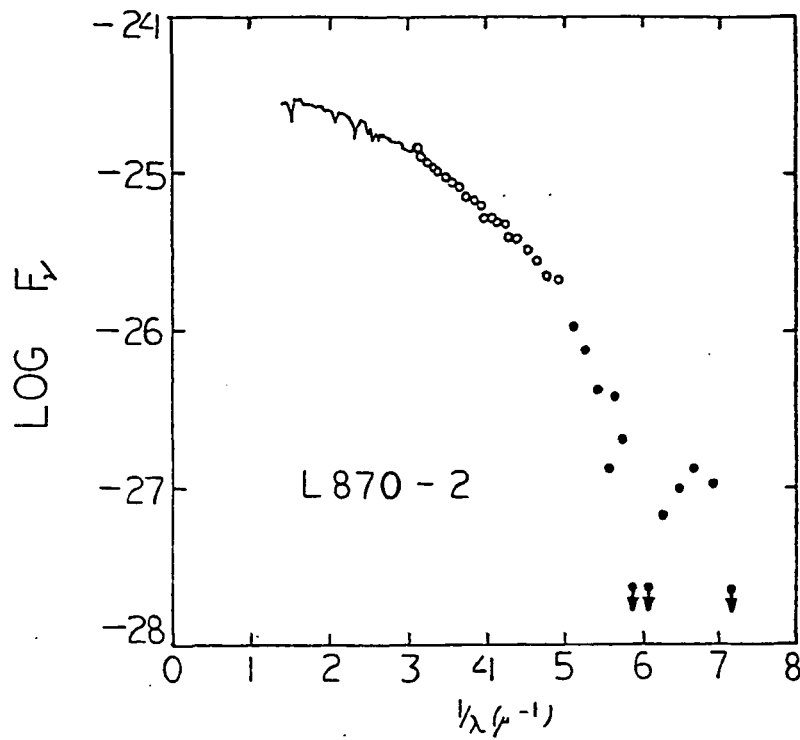


FIG. 2 -

Combined visual and IUE ultra-violet low resolution spectra of the cool DA L870-2. The solid curve is visual data from Oke (1973). Open circles denote LWP data and filled circles are for the SWP.

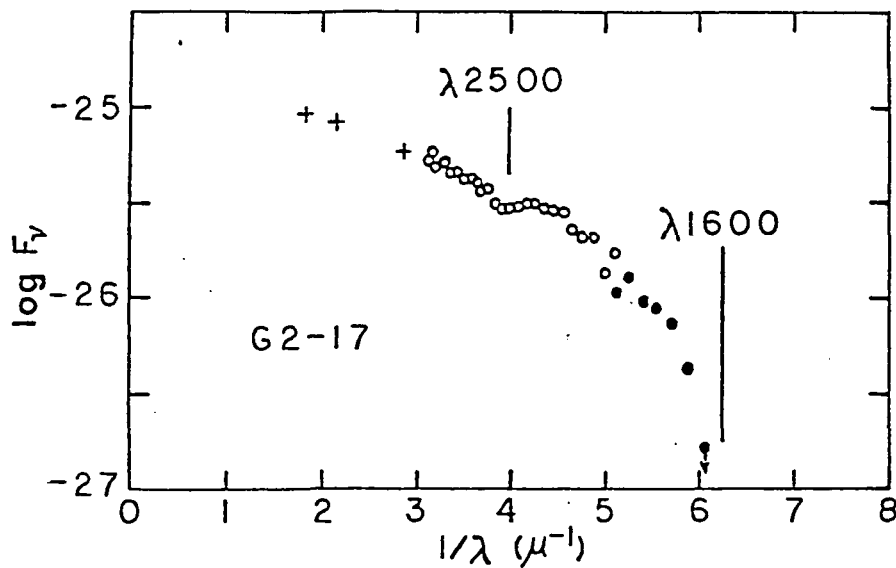


FIG. 3 - The same as Fig. 13, except crosses denote Strömgren photometry from Wegner (1983a). The position of the suspected feature near  $\lambda 2500$  is indicated.

ultraviolet spectral region of the DA white dwarfs in order to understand the presently known quasi-molecular absorptions and to search for new ones.

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## APPENDIX I

## Summary of Research Publications

The following is a list of research papers published since the last Semi-annual Report. All investigations were supported at least partially by NASA Grant NAG5-287. Reprints of the published papers are attached to this document.

A. Published Papers

Liebert, J., Wesemael, F., Sion, E.M., and Wegner, G., "GD323, A White Dwarf with a Stratified H/He Atmosphere," Astrophys. J., **277**, 692 (1984).

Nelan, E.P. and Wegner, G., "Identification of the 1400 and 1600 Å Features in the Ultraviolet Spectra of DA White Dwarfs," Astrophysics, J., **289**, L31, (1985)

Wegner, G., "The Absorption Near 1400 Å in the Spectra of Additional White Dwarfs," Astron. J., **89**, 1050 (1984).

Wegner, G., "The Discontinuity near 1600 Å in the Spectral of DA White Dwarfs," Astrophys. J. (Letters), **281**, 243 (1984).

Wegner, G. and Yackovich, F.H., "The Cool White Dwarf Stein 205 1B," Astrophys. J., **275**, 240 (1983).

B. Papers being Submitted for Publication or in Preparation:

Wegner, G. and Nelan, E.P., "Ultraviolet and Visual Spectroscopy of DB White Dwarf."

C. Abstracts or Titles of Papers Presented at Meetings:

Wegner, G. and Nelan, E.P., "Ultraviolet and Visual Spectroscopy of DB White Dwarfs," Bull. Amer. Astron. Soc., **16**, 510 (1984).

Nelan, E.P. and Wegner, G., "Ultraviolet Features in the Spectra of Cool DA White Dwarfs," Bull. Amer. Astron. Soc., **16**, 510 (1984).

Wegner, G. and Nelan, E.P., "Identification of the 1400 and 1600 Å Features Observed in the Ultraviolet Spectra of DA White Dwarfs," Bul. Amer. Astron. Soc., **16**, 894 (1984).

D. Ph.D. Thesis Completed:

Nelan, E.P., "Ultraviolet Spectra of DA White Dwarfs," Dartmouth College, May, 1985.